

Seismicity and the SWD-C4A well: An ongoing UIC case study in the Denver Basin, Colorado

Ground Water Protection Council
Annual Forum

October 6, 2014



COLORADO
Oil & Gas Conservation
Commission

Department of Natural Resources

Chris Eisinger
Stuart Ellsworth
Bob Koehler

Acknowledgements

- Anne Sheehan, Professor of Geophysics
University of Colorado
- Will Yeck, Matt Weingarten, and Jenny Nakai
University of Colorado

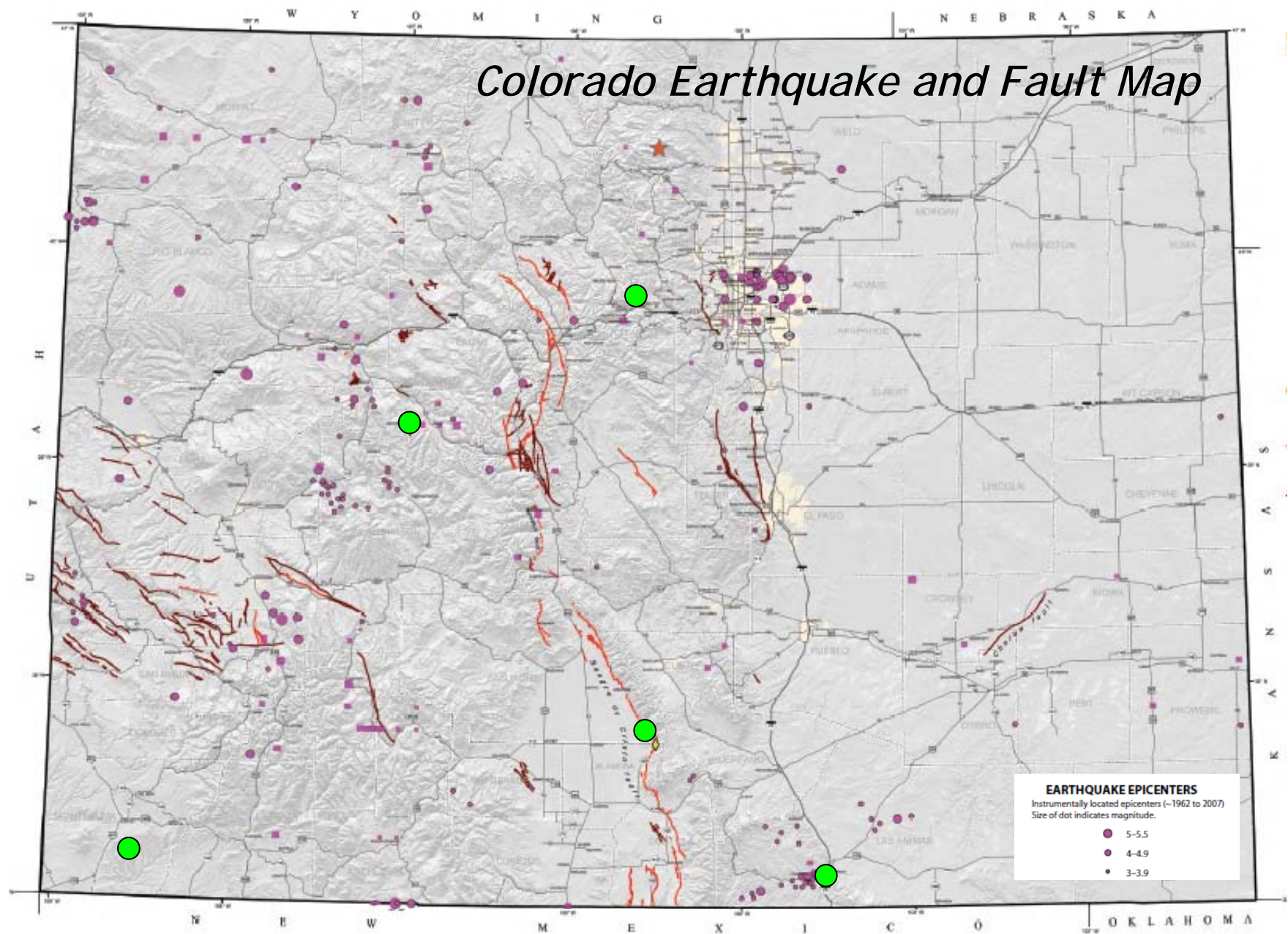
I. Colorado Regional Context

II. Colorado's UIC Program

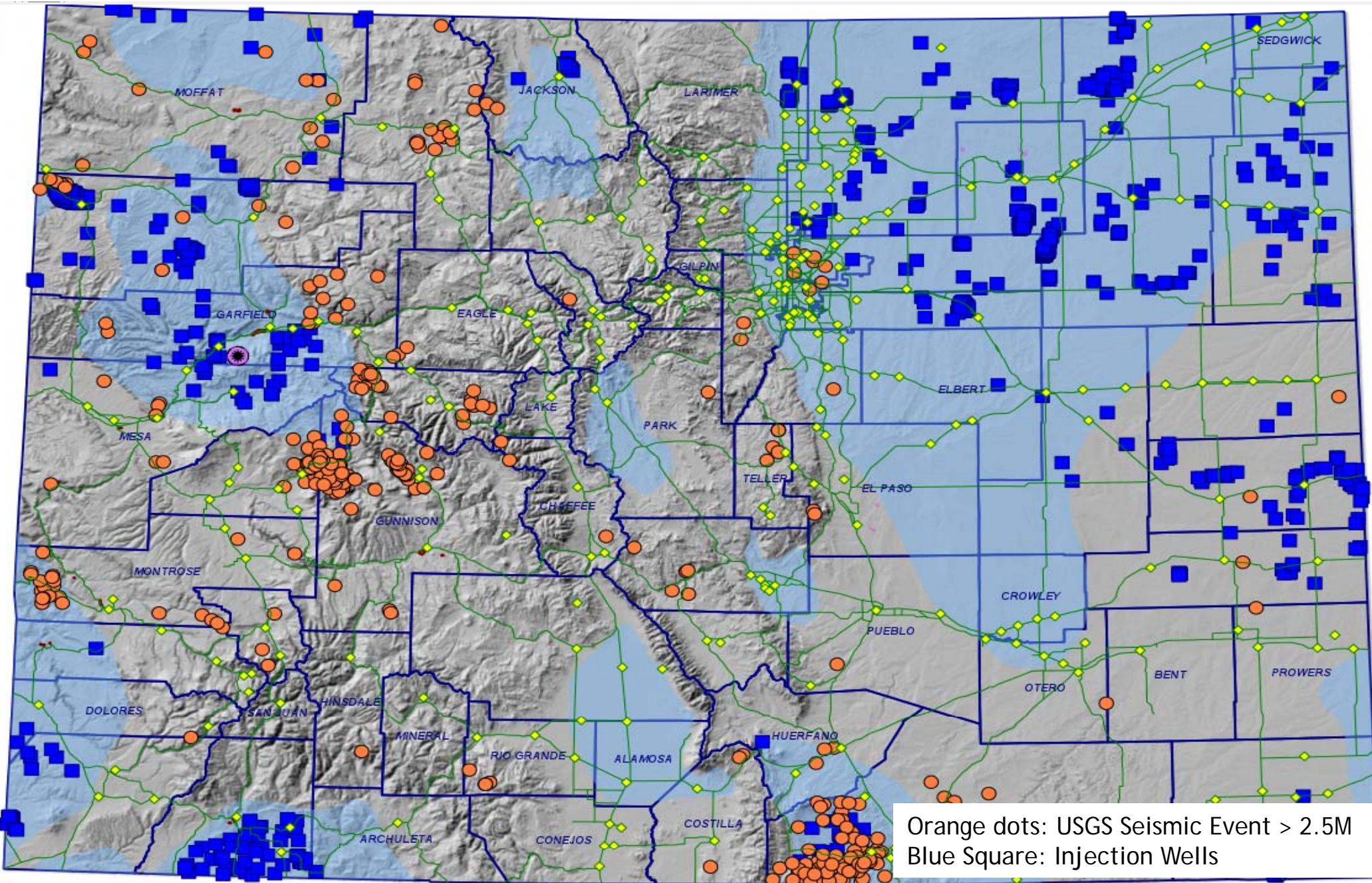
III. The 2014 Greeley Seismic Events and SWD-C4A Well

- *Low damage risk, yet significant public perception*
- *Manageable risk . . .
with regulatory focus on location, volume, rate, pressure, and monitoring.*

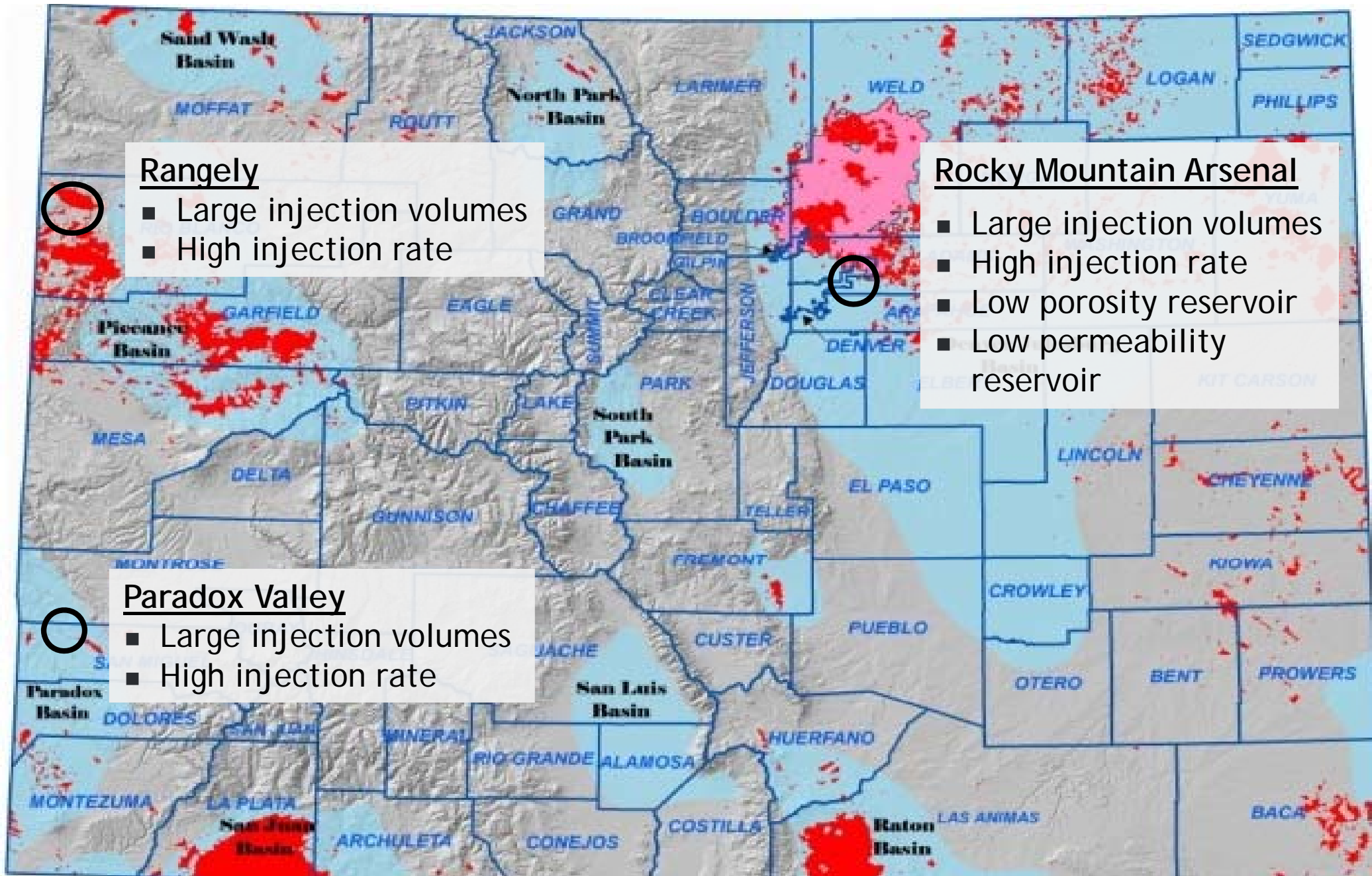
Colorado Regional Context



USGS Seismic Events > 2.5M



Historical Examples of Induced Seismicity in Colorado



Colorado's Underground Injection Program

As of April 1ST 2014, there were 920 UIC wells

350 DISPOSAL WELLS (34 are Tribal)

570 ENHANCED RECOVERY WELLS

UIC Regulations

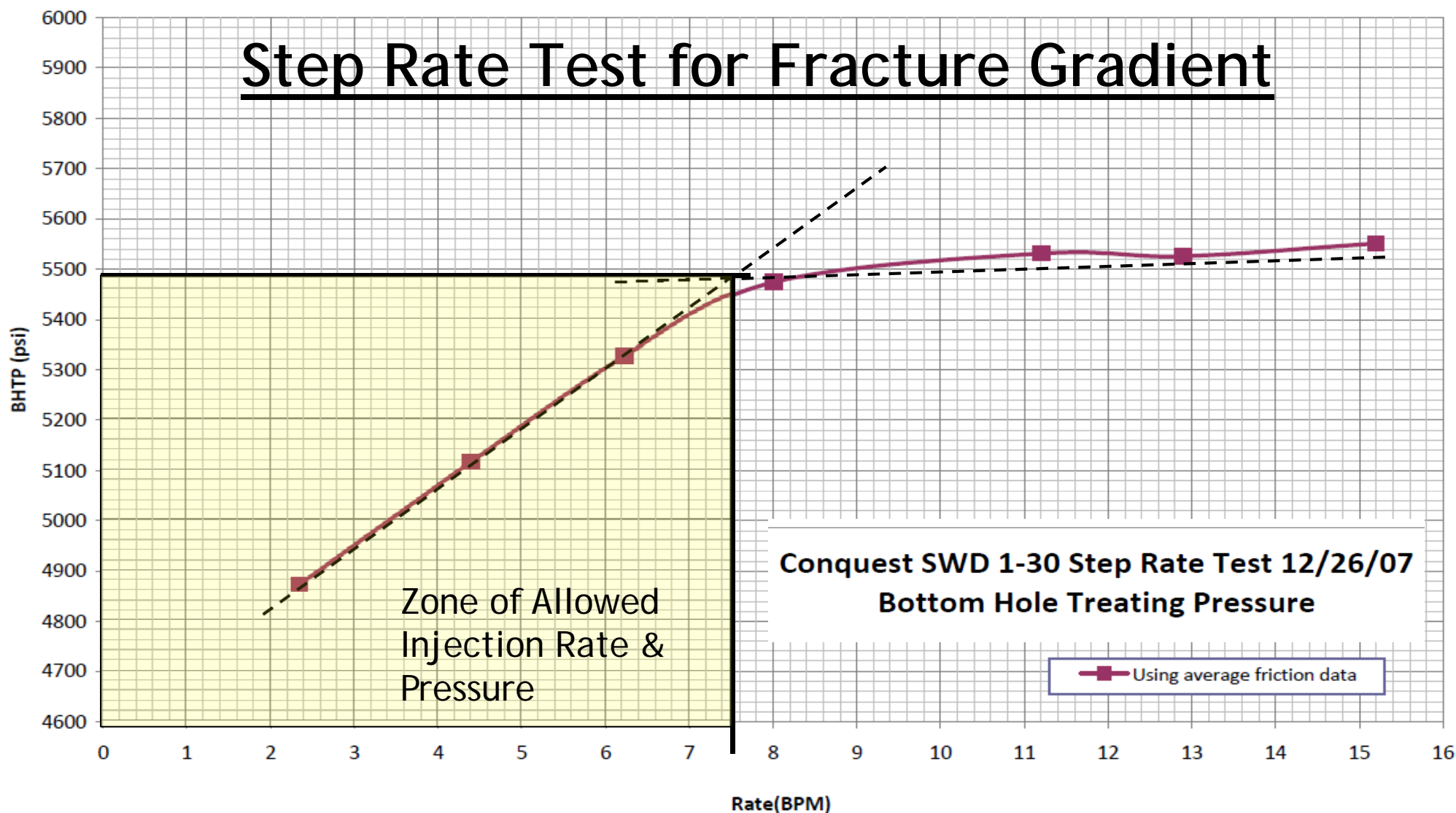
- RULE 325 ADDRESSES UNDERGROUND DISPOSAL OF WATER
- RULES REQUIRE WRITTEN NOTICE TO SURFACE OWNER AND MINERAL OWNER WITHIN ¼ MI
- PUBLICATION OF DISPOSAL WELL NOTICE IN LOCAL NEWSPAPER FOR 30 DAY COMMENT PERIOD
- VARIOUS WELL BORE CONSTRUCTION INFORMATION
- TESTING FOR WATER QUALITY OF DISPOSAL FORMATION. IF TDS IS < 10,000 PPM TDS AN AQUIFER EXEMPTION IS REQUIRED
- FOR ENHANCED RECOVERY OPERATIONS THESE STEPS ARE DONE OVER THE ENTIRE UNIT AREA
- WELL CONSTRUCTION REVIEW FOR FLUID ISOLATION AND WELLBORE INTEGRITY

UIC Data Review

1. REVIEW THE DRILLING RECORDS FOR:
 - a) DAILY DRILLING LOGS
 - b) DRILLING BREAKS
 - c) LOST CIRCULATION ZONES
 - d) RATE OF PENETRATION CURVES (ROP)
2. REQUEST A TRANSIENT TEST TO DETERMINE INJECTION RATES AND PERMEABILITY
3. STATIC WATER LEVEL MEASUREMENT

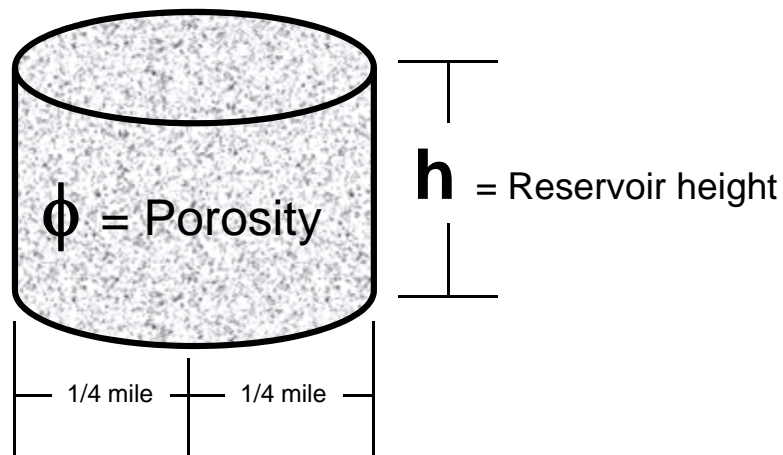
1) *Standard Condition of Approval:* *< Maximum Allowable Injection Rate & Pressure*

Step Rate Test for Fracture Gradient



2) *Standard Condition of Approval:*
< Maximum Allowable Injection Volume

$$MIV = \phi h \pi (1/4 \text{ mile})^2$$



ϕ = Porosity

h = Reservoir height

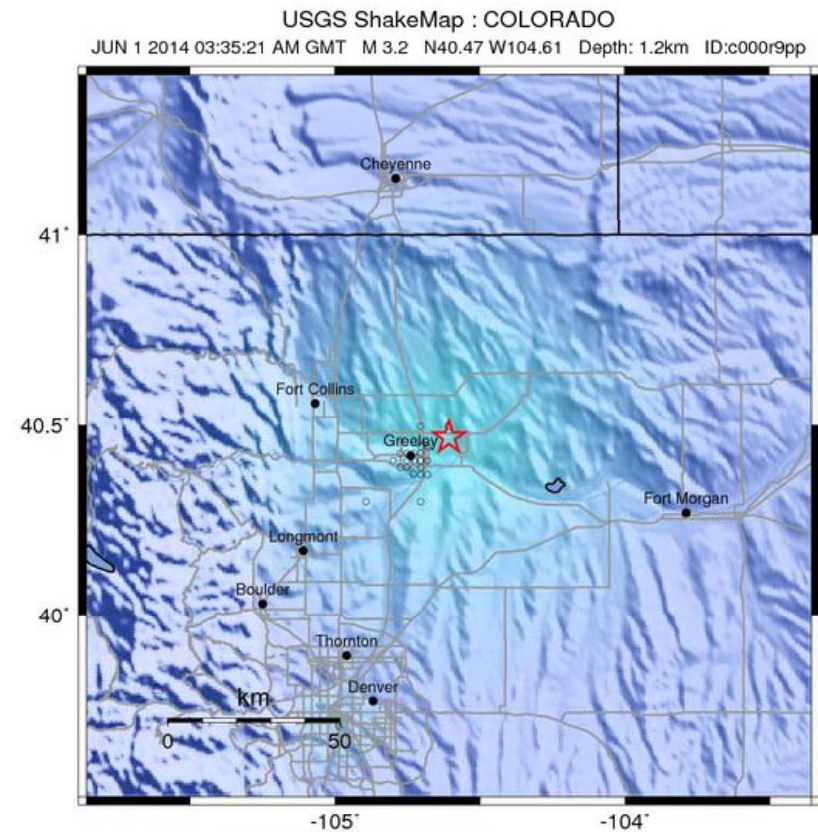
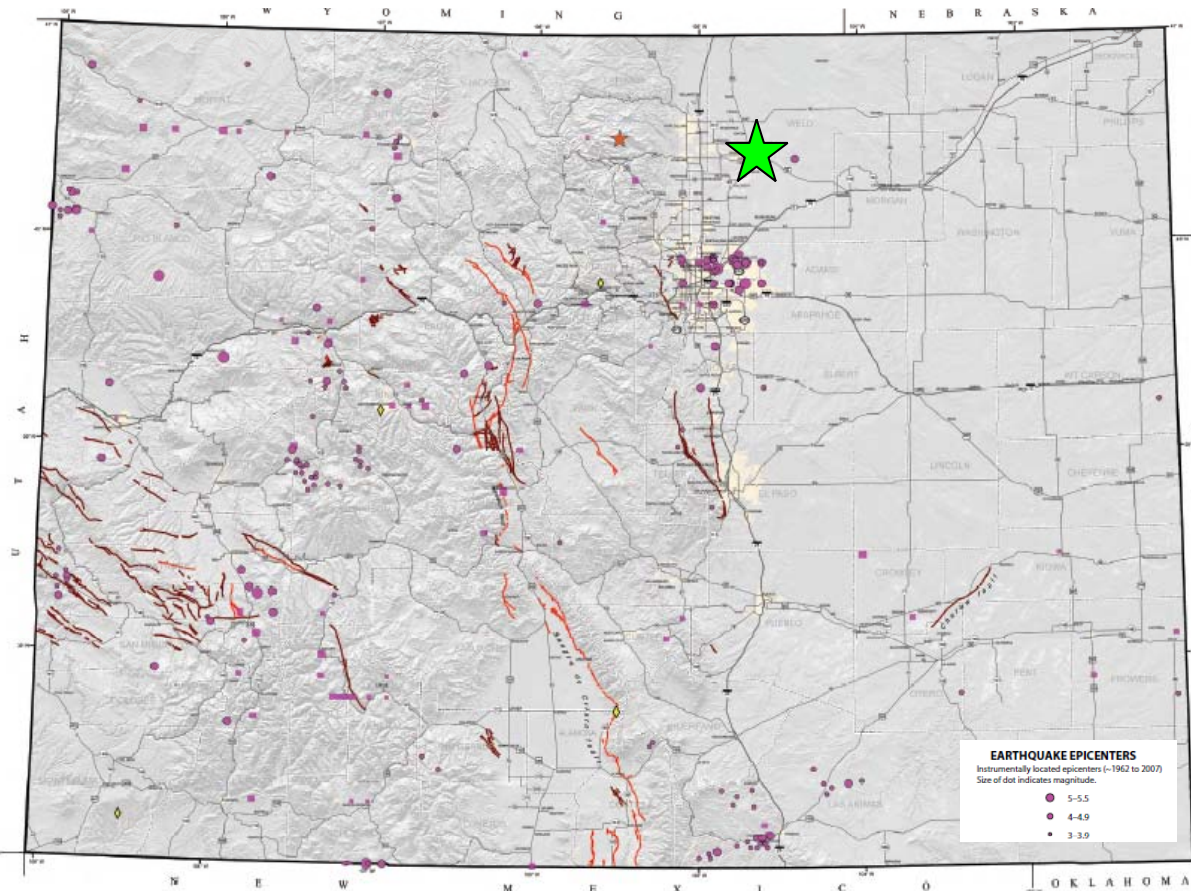
π = PI

Additional Safeguards

- Review of seismicity and PGA
- Review of geology, subsurface data
- DWR review for of injection zone
- Special data, test or logs periodically required:
 - Bradenhead test
 - Temperature, radioactive or noise logs
 - Cased hole integrity logs
 - Transit Analysis.

2014 Greeley Seismic Events and SWD-C4A Well

May 31st at ~9:35PM
6 miles NE of Greeley Colorado
M 3.2 Event

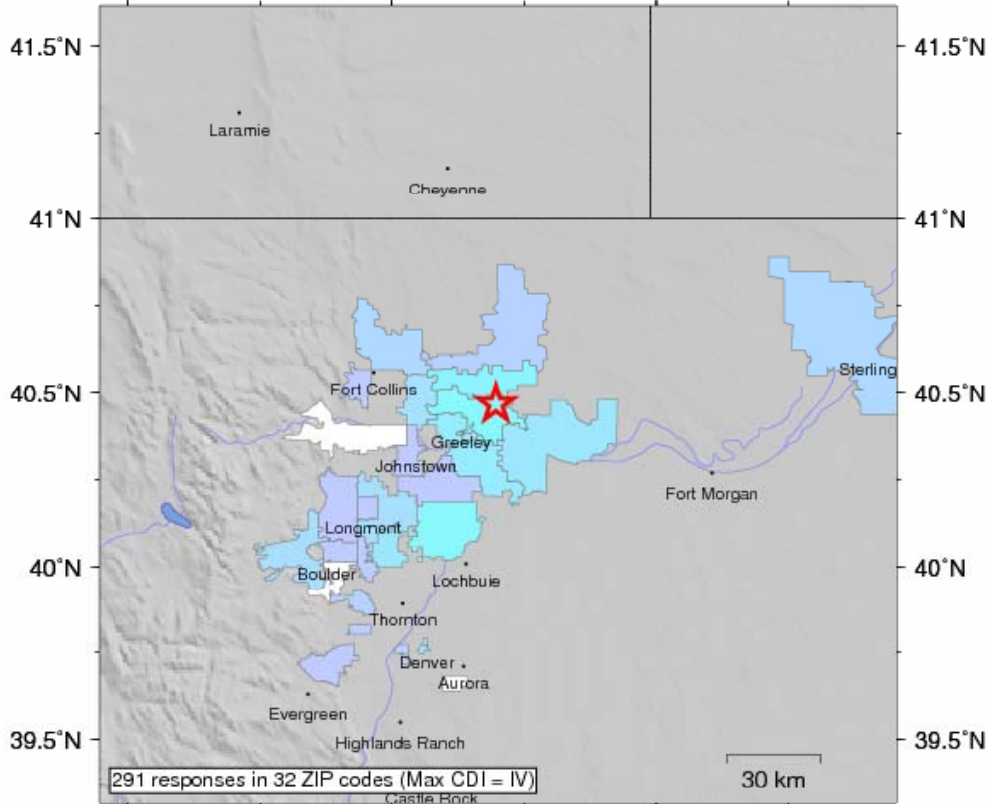


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%)	<0.007	0.08	1.0	5.0	8.8	15	27	47	>83
PEAK VEL.(cm/s)	<0.003	0.04	0.5	3.0	6.5	14	30	63	>136
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Atkinson & Kaka, 2007

USGS Community Internet Intensity Map COLORADO

May 31 2014 09:35:21 PM local 40.4674N 104.6079W M3.2 Depth: 1 km ID:usc000r9pp

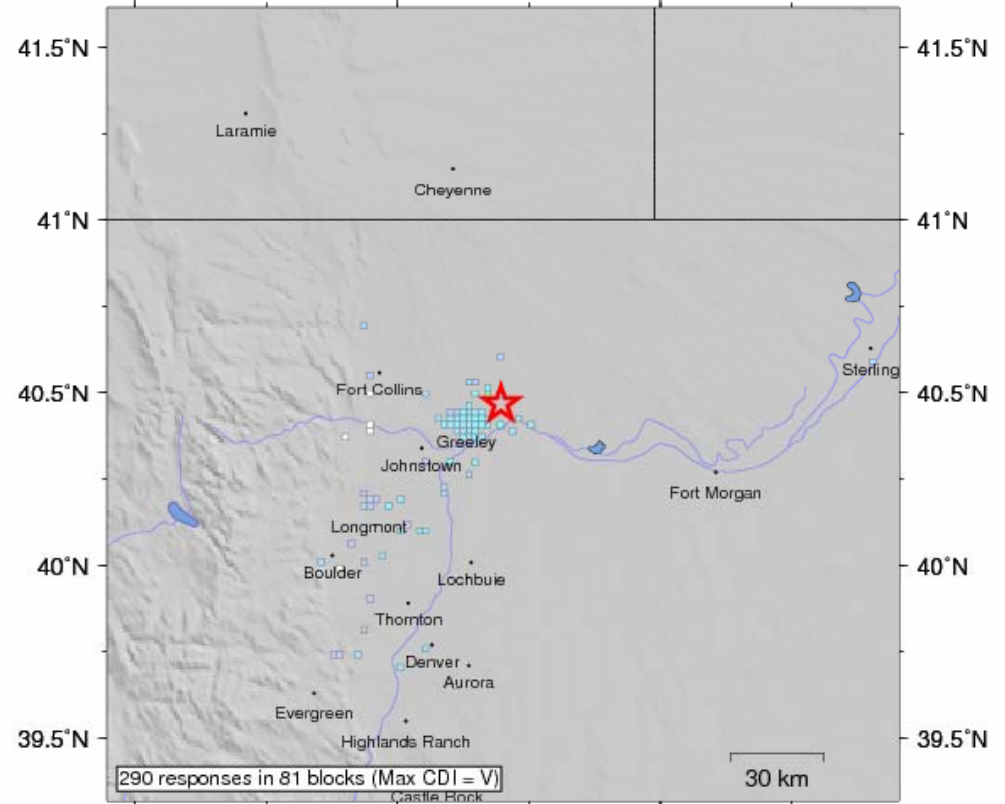


INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Processed: Sat Aug 16 11:07:47 2014

USGS Community Internet Intensity Map COLORADO

May 31 2014 09:35:21 PM local 40.4674N 104.6079W M3.2 Depth: 1 km ID:usc000r9pp

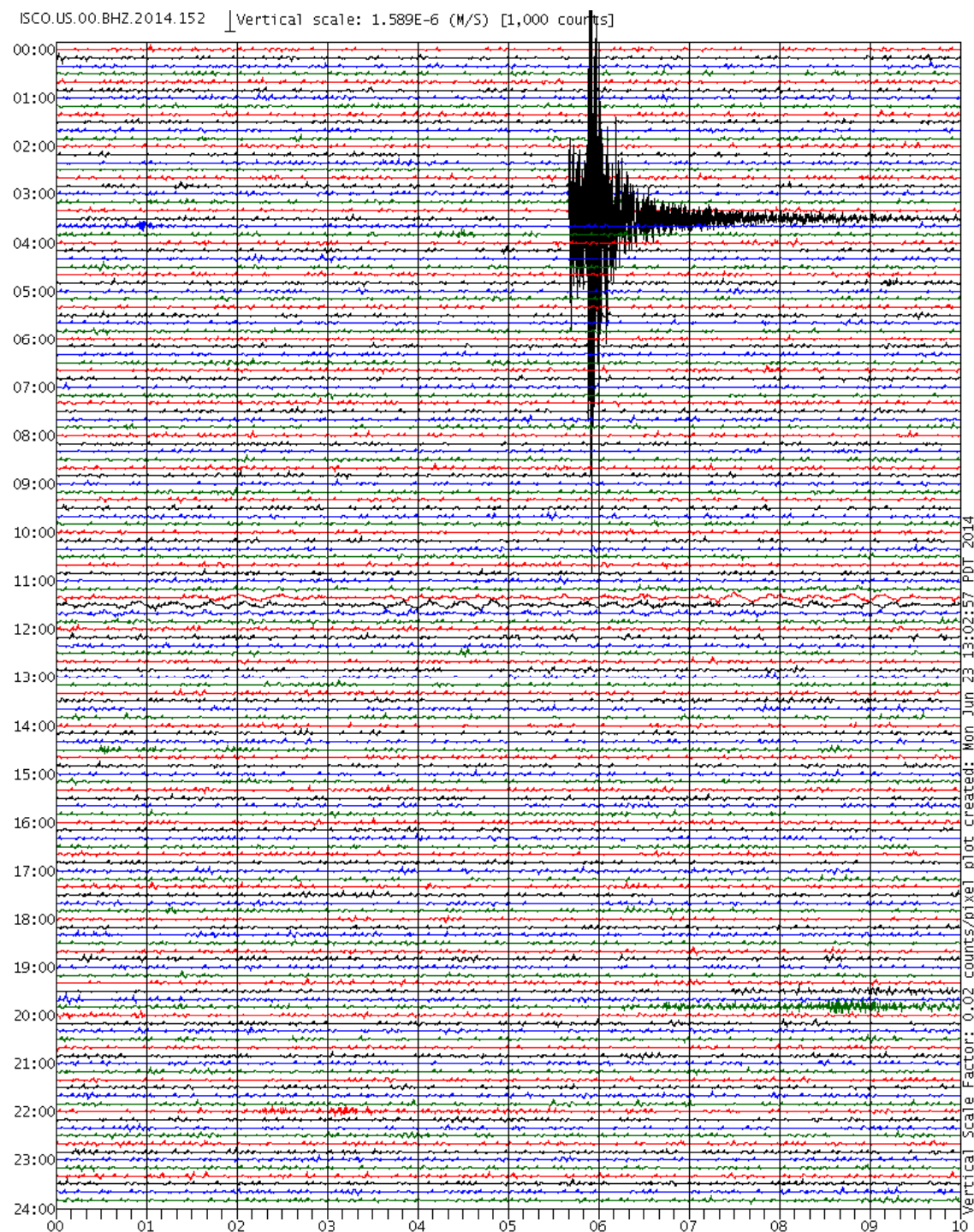


INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Processed: Sat Aug 16 11:07:51 2014

USGS: Did you feel it?

Anne Sheehan et al.
University of Colorado



Greeley May 31st quake as detected on closest seismograph station (USGS ISCO) ~70 miles away at Idaho Springs.

Anne Sheehan et al.
University of Colorado

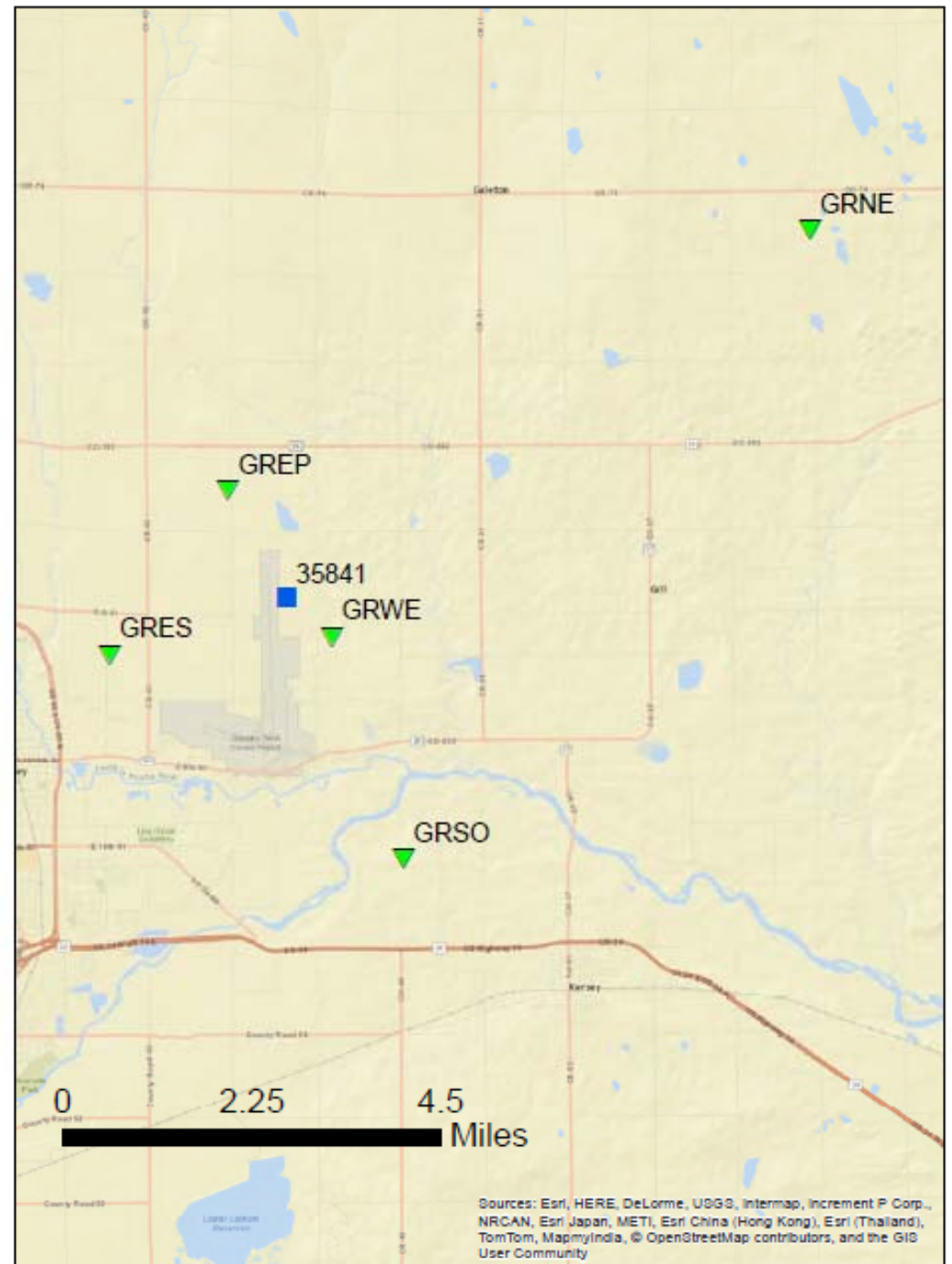
Baseline Seismicity

- M 4.2 event in 1969 located 12 miles SW of injection site recorded in USGS database.
- Matched filter study to retrospectively search for waveforms matching M 3.2 event at ISCO station from January 2013 - May 2014:
 - *First event a M 0.74 in November, 2013*
 - *Eleven more events between January and end of May, 2014 (ranging from M 0.56 to M 2.3)*

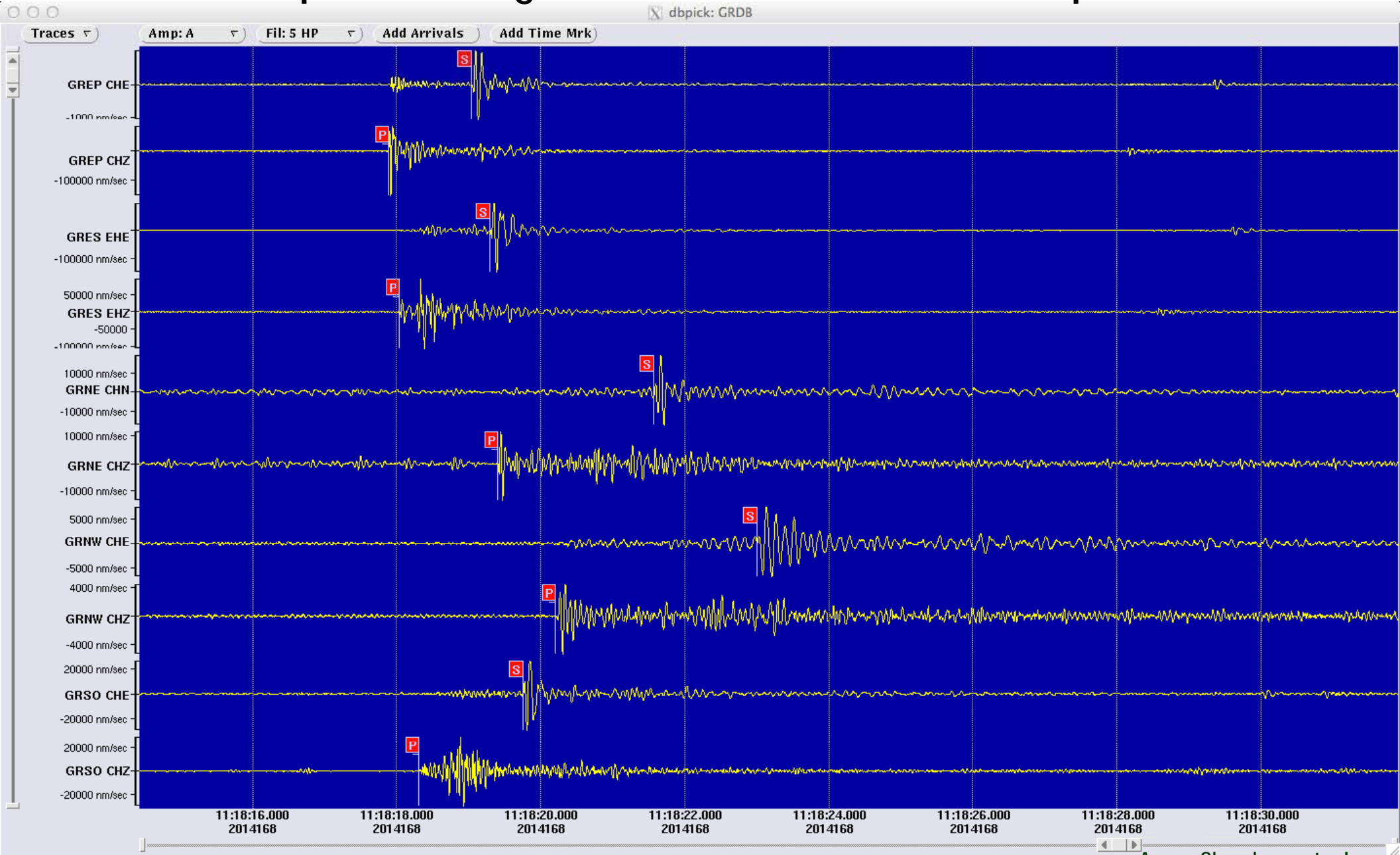
University of Colorado installs portable broadband seismometers in early June



Anne Sheehan et al.
University of Colorado



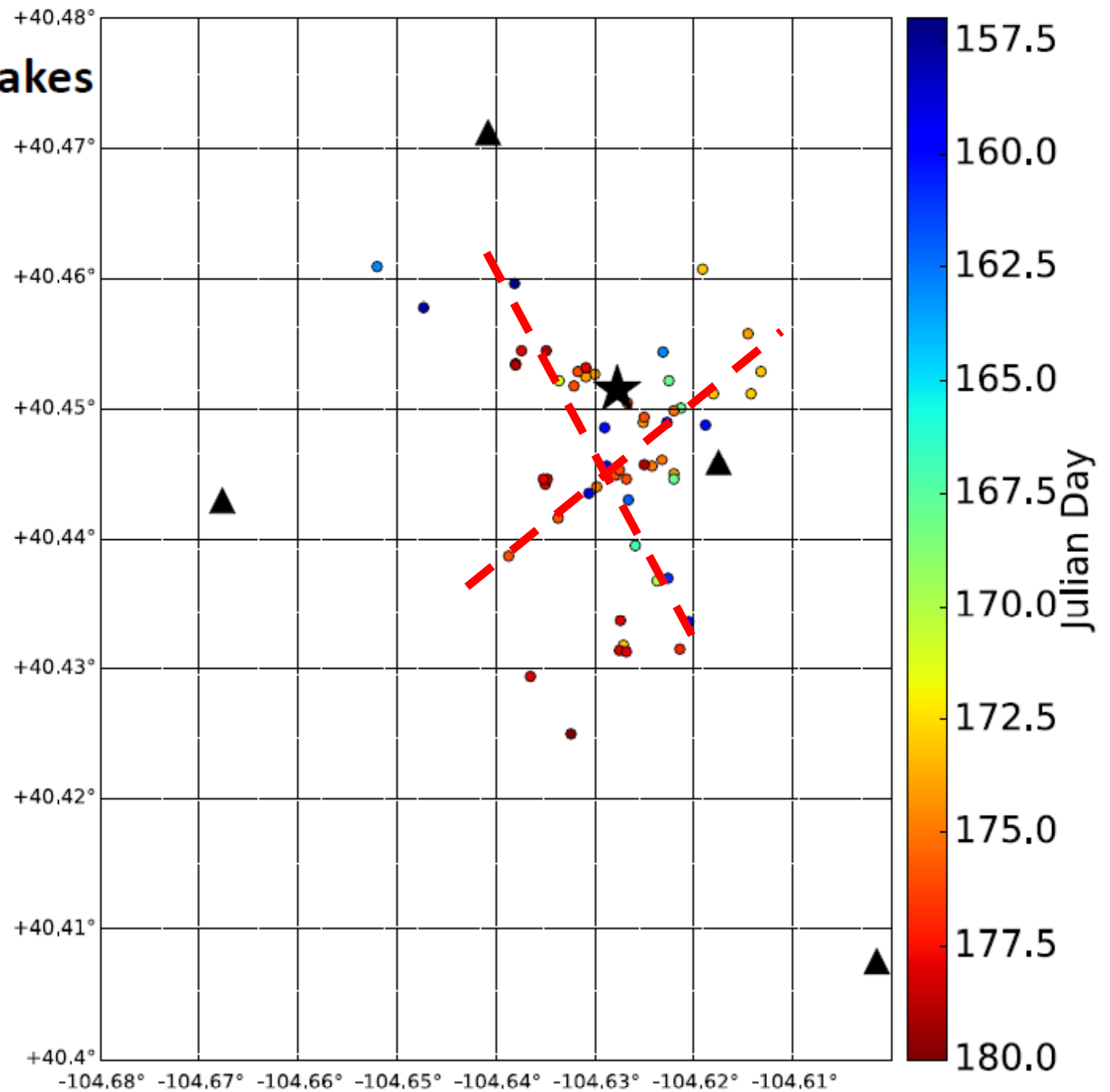
Sample seismograms from 5 stations with picks



Anne Sheehan et al.
University of Colorado

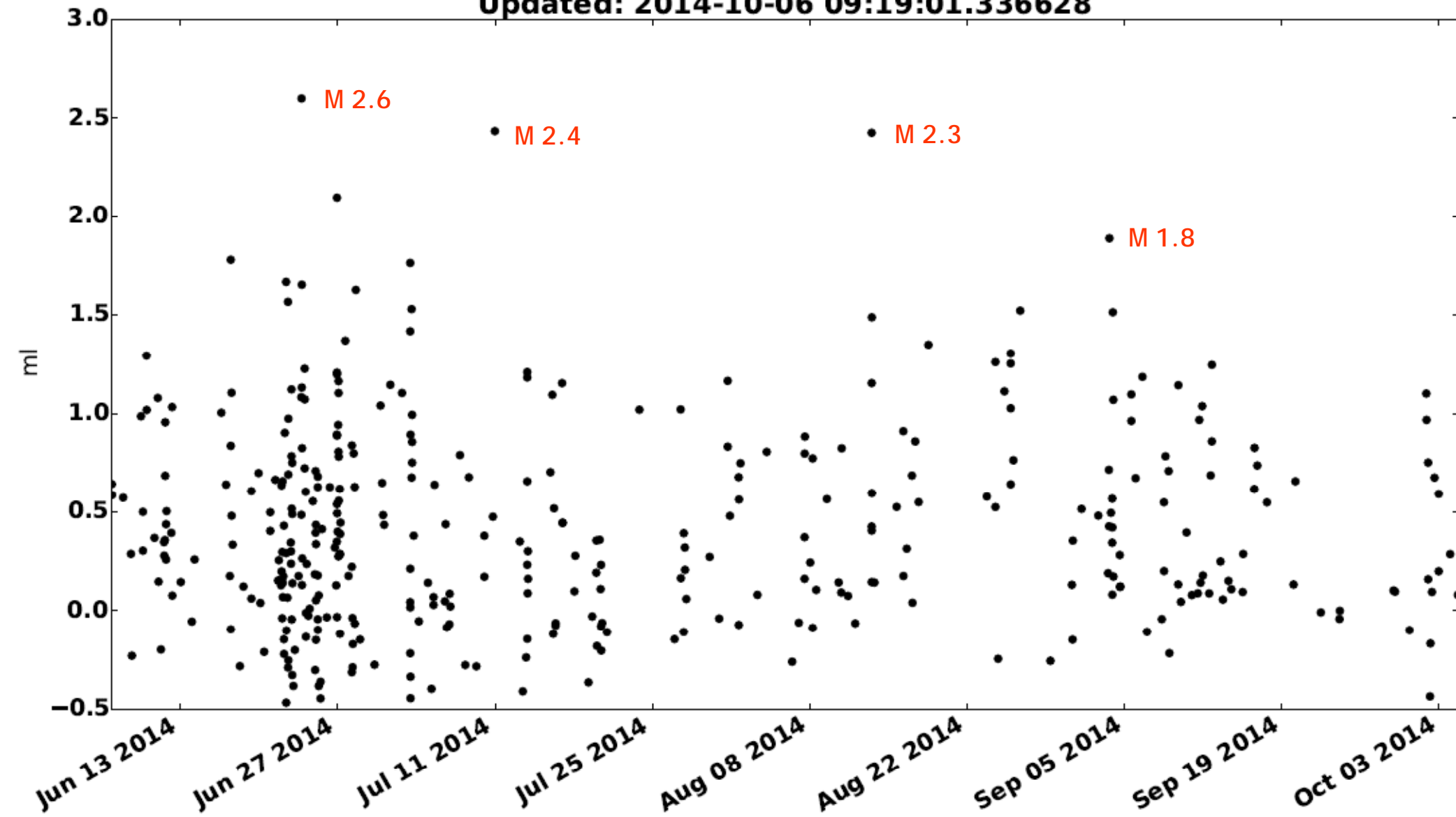
June 8-29 earthquakes

Colored by day



COGCC interpretation after
Anne Sheehan et al.
University of Colorado

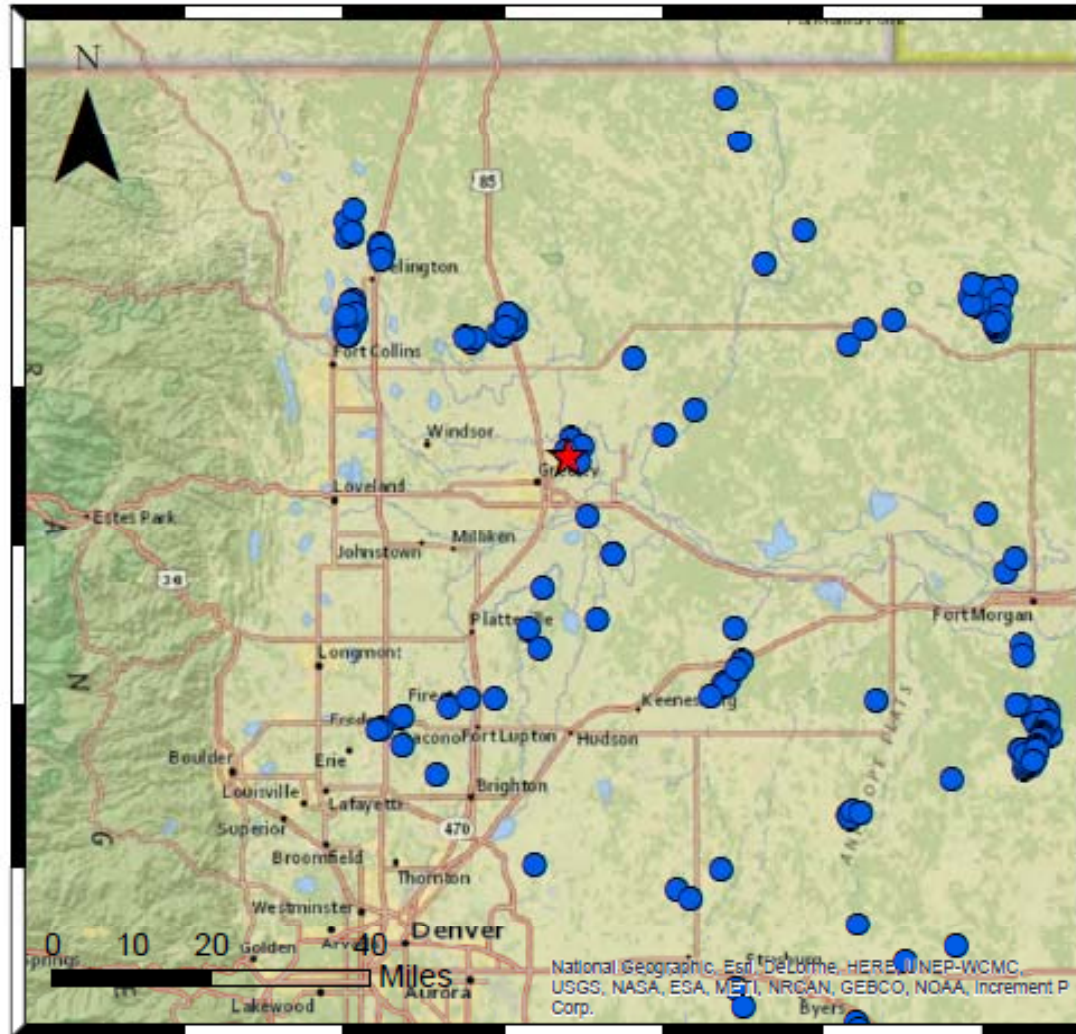
Updated: 2014-10-06 09:19:01.336628



Anne Sheehan and William Yeck
University of Colorado

Class II Injection wells (blue circles) in NE Colorado

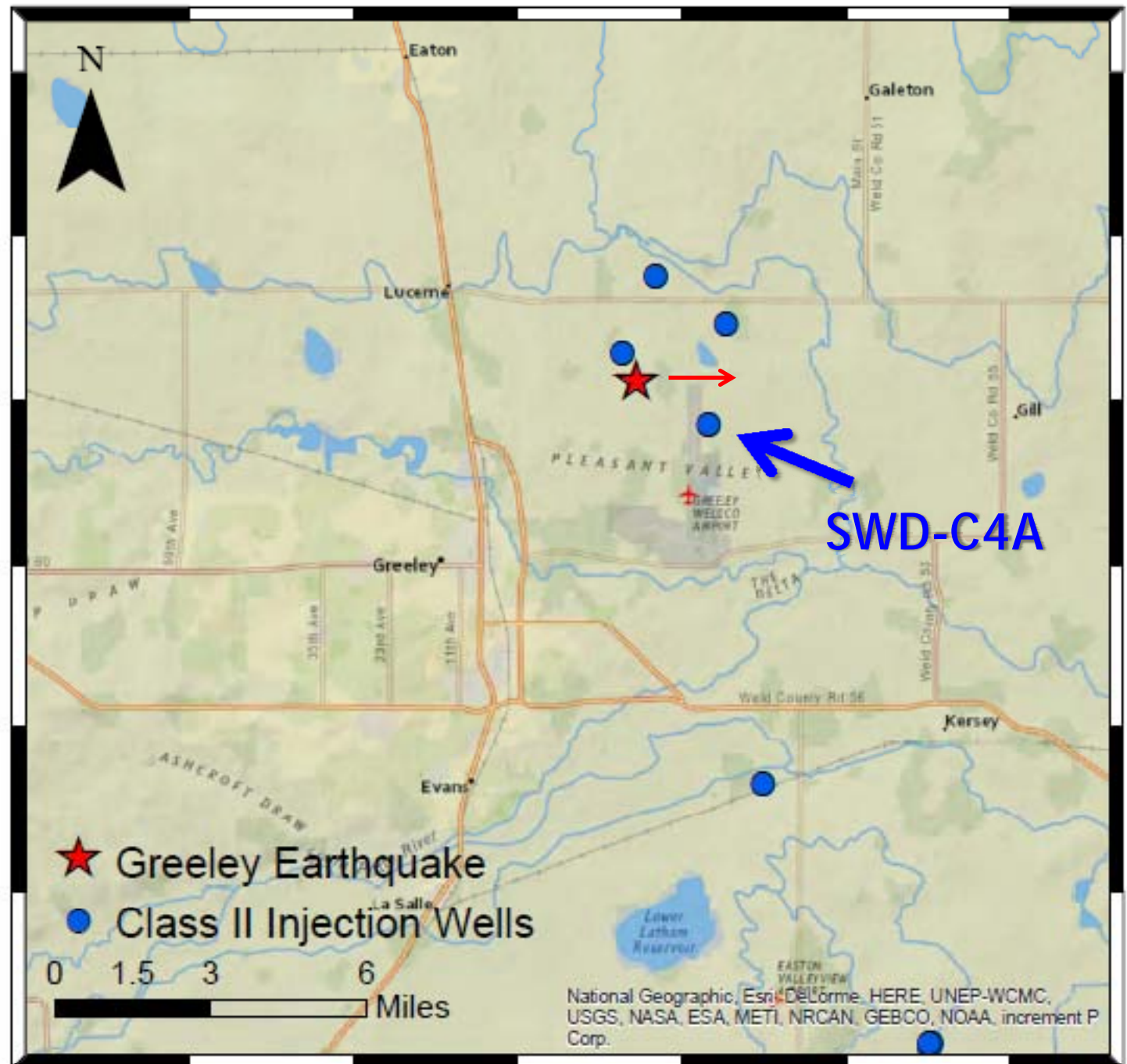
Red star is earthquake epicenter



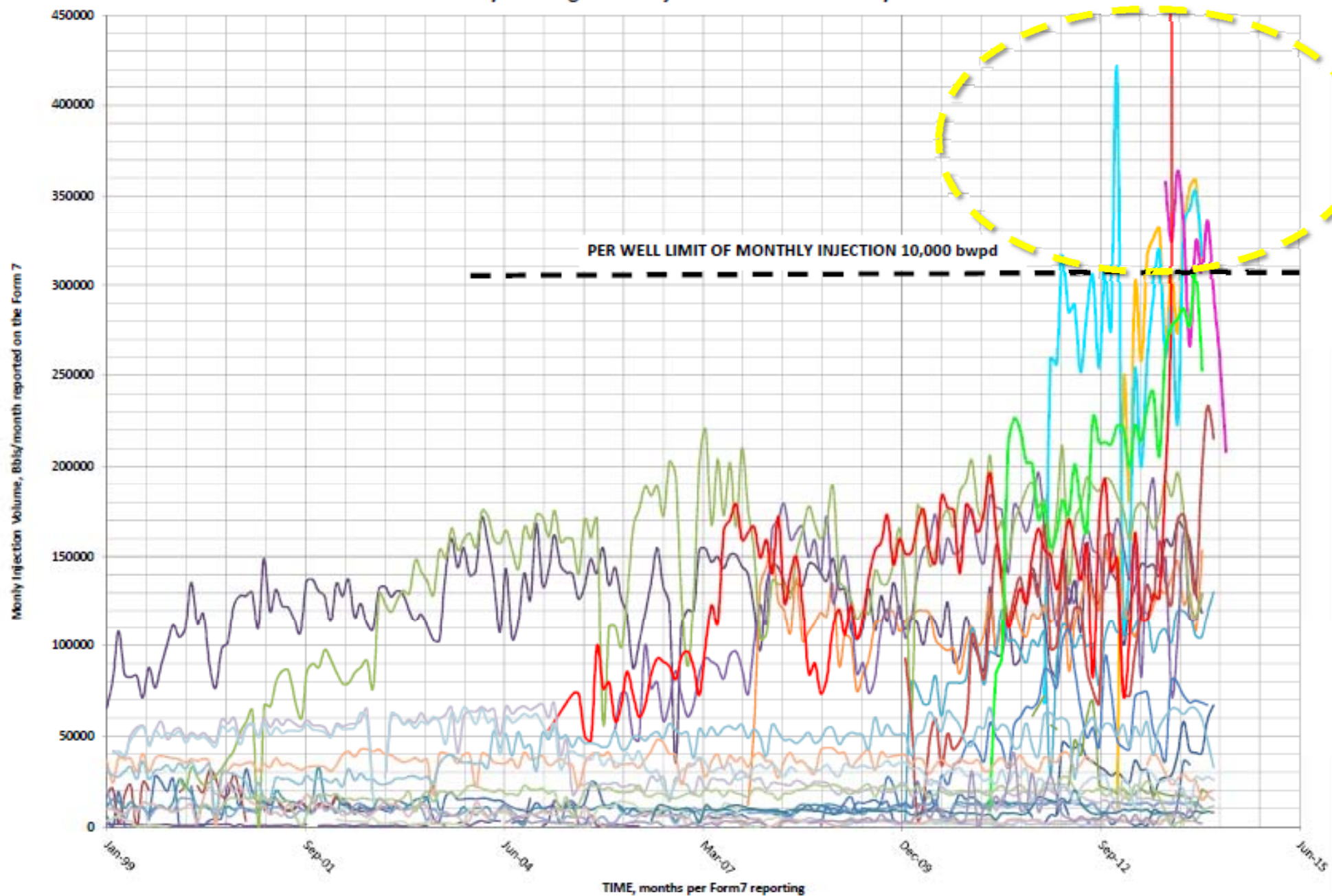
- ★ Greeley Earthquake
- Class II Injection Wells

Anne Sheehan et al.
University of Colorado

Anne Sheehan et al.
University of Colorado



Monthly Underground Injection in Weld County



NGL's SWD-C4A Well

- Commercial disposal well drilled in Weld County located in the Denver Basin (handle flowback associated with Niobara shale play)
- Total depth: 10,818'
- Injection volume (Aug 2013 - May 2014): ~260-360k Bbls per month
- Permitted max pressure: 1,512 psi
- Perforated formations: Permian Lyons through Pennsylvanian Fountain Formation
- Fountain Formation sits on top of basement, zones of injection were initially <500' from basement
- Area is known to have a complex network of antithetic-synthetic faults originating in basement

C4A Well - Time Table

1. *Drilled & completed: 12/15/2012*
2. *UIC Permit approved: 03/22/2013*
3. *Injection began: 04/2013*
4. *Seismic Events:*
 - a. *First USGS reported, M3.2: 05/31/2014*
 - b. *Second USGS reported, M2.6: 06/23/2014*
5. *C4A Shut-in for 20-DAYS: 06/23/2014*
6. *Reinjection begins @ 5,000 bpd: 07/19/2014*
7. *Injection increased to ~7,5000 bpd: 08/07/2014*
8. *Injection increased to ~9,500 bpd: 10/03/2014*

WELLBORE DIAGRAM
High Sierra Water Services
SWD #C4A

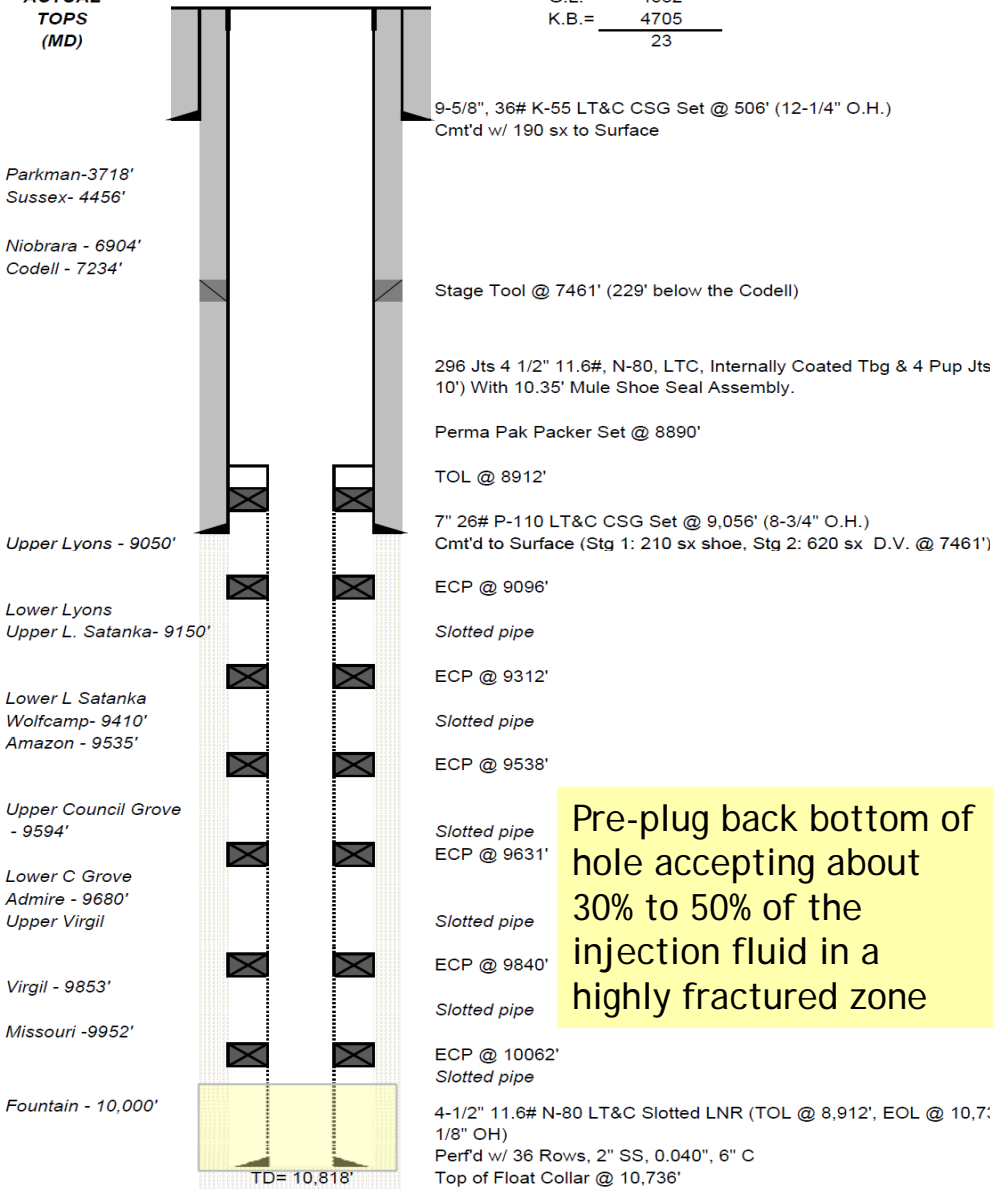
SWSE, Sec. 26, T6N, R65W
Weld County, CO
SHL: 1040' FSL, 1924' FEL
BHL: 1089' FNL, 1471' FEL
API #: 05-123-35841

Directions: WCR 47 at WCR 64, 0.4 mi West, N into

ACTUAL W/ ECP SETTING DEPTH

ACTUAL
TOPS
(MD)

G.L.= 4682
K.B.= 4705
23



Pre-plug back bottom of
hole accepting about
30% to 50% of the
injection fluid in a
highly fractured zone

WELLBORE DIAGRAM
High Sierra Water Services
SWD #C4A

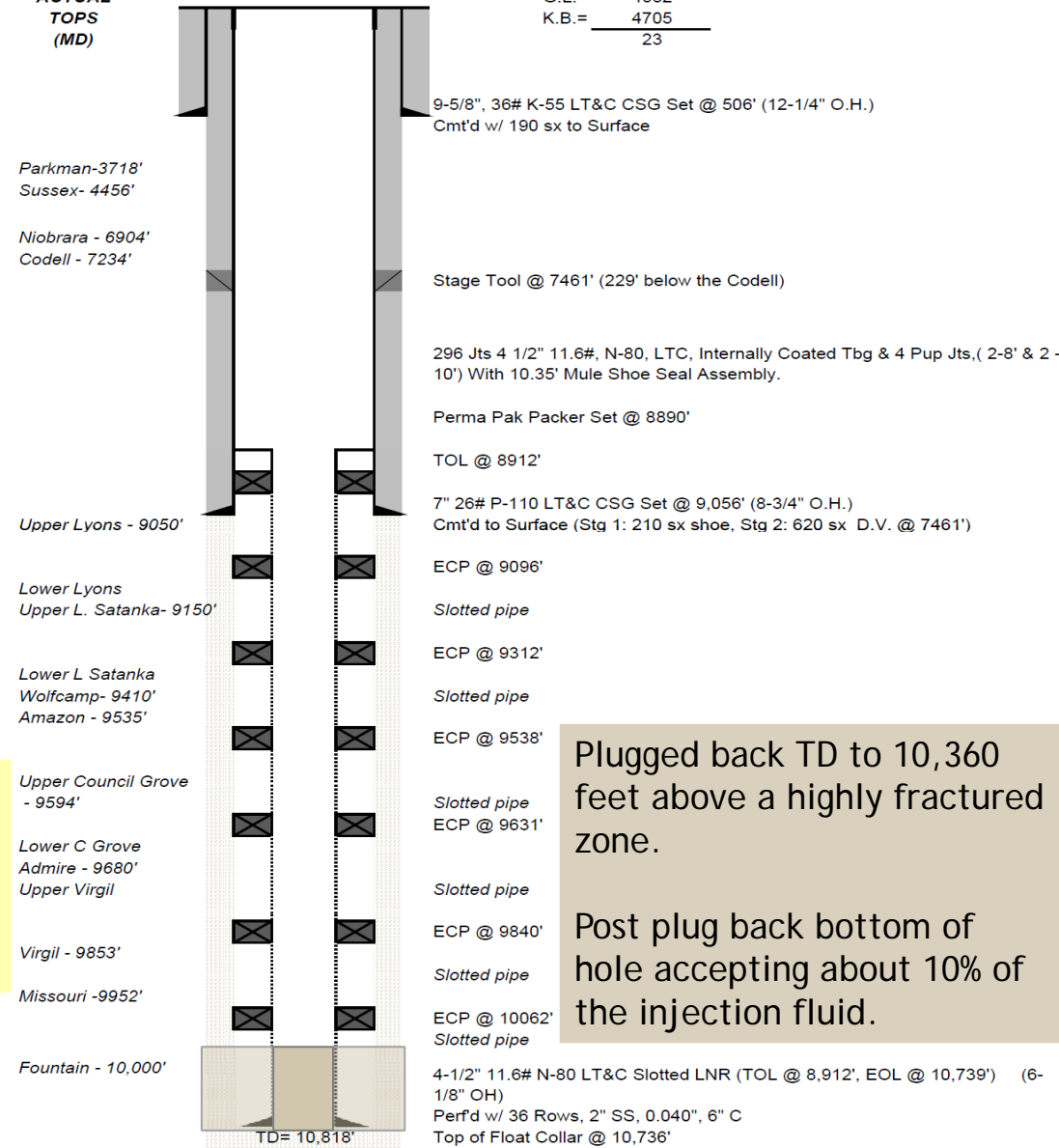
SWSE, Sec. 26, T6N, R65W
Weld County, CO
SHL: 1040' FSL, 1924' FEL
BHL: 1089' FNL, 1471' FEL
API #: 05-123-35841

Directions: WCR 47 at WCR 64, 0.4 mi West, N into

ACTUAL W/ ECP SETTING DEPTHS

ACTUAL
TOPS
(MD)

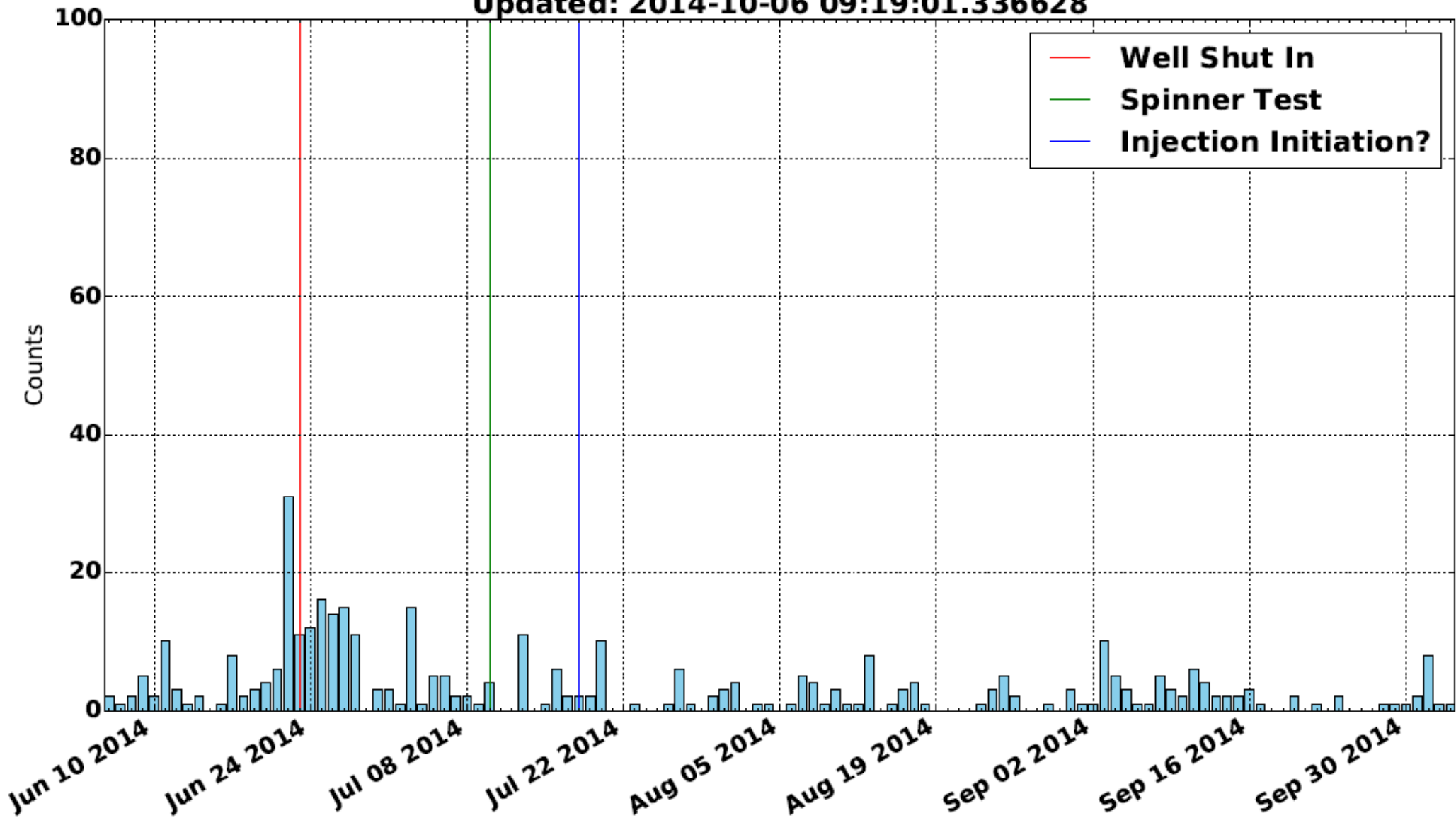
G.L.= 4682
K.B.= 4705
23



Plugged back TD to 10,360
feet above a highly fractured
zone.

Post plug back bottom of
hole accepting about 10% of
the injection fluid.

Updated: 2014-10-06 09:19:01.336628



Anne Sheehan and William Yeck
University of Colorado

Planning - Risk Management Plan: Traffic Lights

Green

Continue operations – no seismicity felt at surface (MMI I-II)*

– Less than M2.5 within 2.5 Miles

Amber

Modify operations – seismicity felt at surface (MMI II-III+)*

– Greater than M2.5 & Less than 4.4 within 2.5 Miles

Red

Suspend operations – seismicity felt at surface with distress and/or damage (MMI V+)*

– Greater than M4.5 within 2.5 Miles

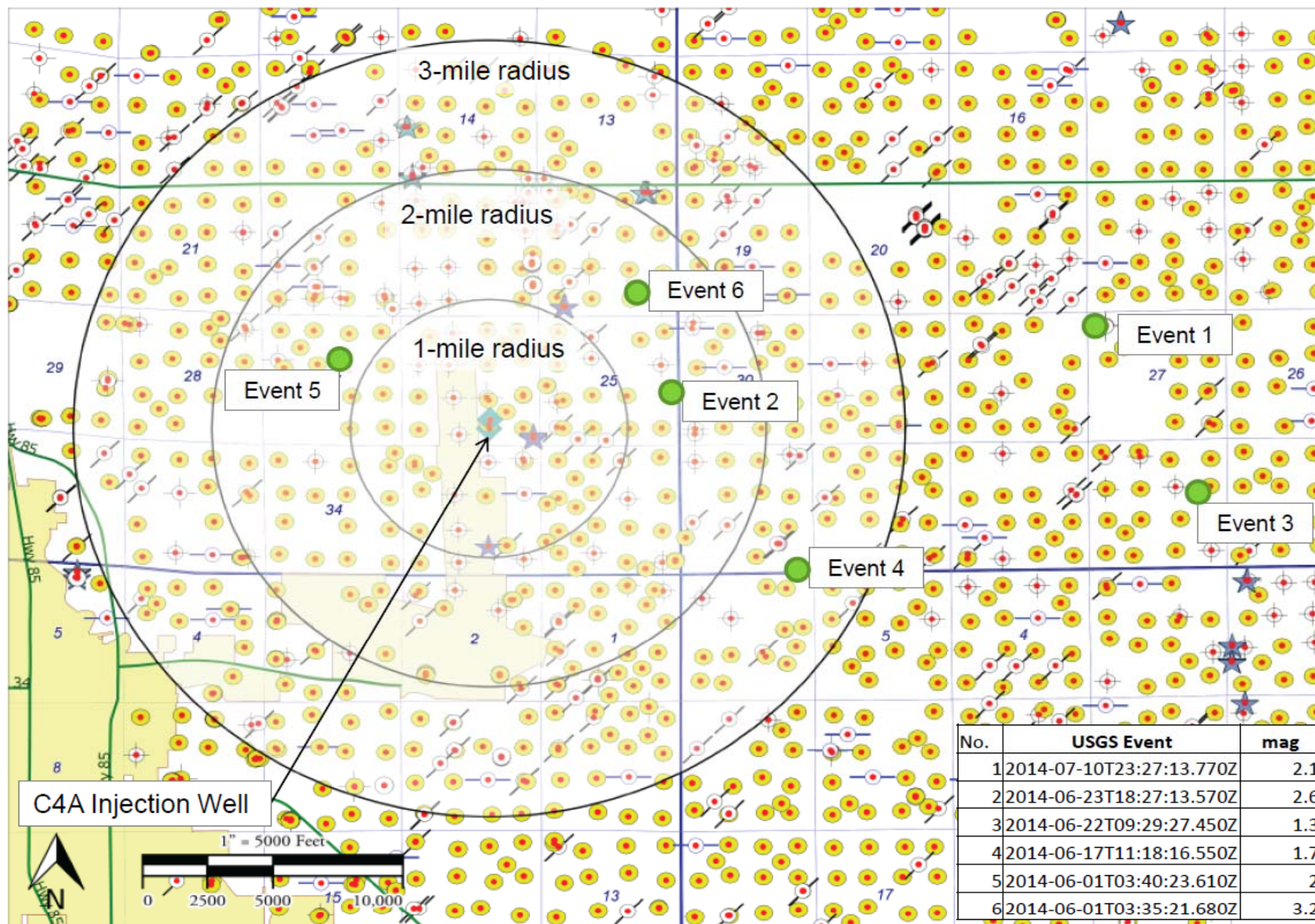
Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	none	none	none	Very Light	Light	Moderate	Moderate Heavy	Heavy	Very Heavy
Peak Acceleration (%g)	<0.17	0.17 to 1.4	1.4 to 3.9	3.9 to 9.2	9.2 to 18	18 to 34	34 to 65	65 to 124	>124
Peak Velocity (cm/s)	<0.1	0.1 to 1.1	1.1 to 3.4	3.4 to 8.1	8.1 to 16	13 to 31	31 to 60	60 to 116	>116
Magnitude	1 – 2.9	3 – 3.9	4 – 4.4	4.5 – 4.9	5 – 5.4	5.5 – 5.9	6 – 6.4	6.5 – 6.9	7.0+
Modified Mercalli	I	II to III	IV	V	VI	VII	VIII	IX	X+
Traffic Lights *	Green			Amber			Red		

Exhibit 1

* Established based upon local conditions, demographics and codes

AXPC / Industry induced seismicity SME presentation

3-mile radius around C4A injection well



C4A Authorized To Re-inject

1. AXP Traffic Light criteria will apply.
2. Injection resumes at 5,000 barrels of water per day (BWPD) with a maximum injection pressure of 1,512 psi. for 20 days.
3. If no M 2.5 seismic events may increase to 7,500 BWPD at 1,512 psi. for 20 days.
4. If no M 2.5 seismic events for 20 days NGL may request an increased injection rate.
5. NGL will install a permanent seismometer station near the Well.

Take-Away Thoughts

1. Although there is strong temporal and spatial data to suggest seismic events were induced by the SWD-C4A well, the link is not definitive.
2. In Colorado, these low magnitude earthquakes have a high public perception, due to the location and possible linkage to wastewater disposal.
3. The COGCC, by regulating location, volume, pressure, rate, and monitoring seismic activity, views the risk of induced seismicity as manageable.

Questions?



COLORADO

Oil & Gas Conservation
Commission

Department of Natural Resources

chris.eisinger@state.co.us